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"FUNDAMENTAL STUDIES RELATING PARTICLE SIZE EFFECTS TO INFRARED SPECTRA"

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Research contained in this report was performed under NGR-05-020-237  
in accordance with the time allocation of staff shown herein.

## I. INTRODUCTION

This report is the first semi-annual report on NASA Grant No. NGR-05-020-237, and is a statement of the work performed so far, as requested in the grant award.

The level of effort on the contract has been comparatively low during the first six months, being approximately 3.3 man months of professional effort plus secretarial, technician and student help. The emphasis has been (a) streamlining the data taking and processing techniques so that rapid and economical spectra can be reduced later in the program. This effort has run in parallel with similar endeavors on other projects at the Remote Sensing Laboratory and (b) finalizing the construction of a Circular Variable Filter spectrometer (CVF) whose data output is immediately compatible with the IBM 360 computer for use on this program.

## II. SPECTRA OF POWDERED ROCKS

In the early stages of the grant it was clear from the literature that the spectra of powdered samples would not be easy to collect with any accuracy, since the spectral departures became very subtle when the powder size becomes comparable with the wavelength of the emitted radiation. Nevertheless, a number of samples, of differing powder sizes and compositions were examined with the SG-4 spectrometer, in order to estimate the severity of the problem.

The powders were taken outdoors where they could radiate into a cold sky, and the experimental procedure was similar to that used in the field, except that an X-Y plotter was used to record the data. These plots were subsequently digitized on a CALMA digitizer, and the data fed into the computer.

The results from this early experiment were disappointing in that the spectra were dominated by noise. Whether this noise arose from the instrumentation or the digitizing process is not clear, but it was evident that we would not be able to use such short cuts

successfully. Before attempting to take such spectra again, we therefore decided to try and improve both our experimental technique and our equipment.

### III. KNOWN ROCK SPECTRA

A series of spectra of well known 'library' rocks were taken to examine the sensitivity to emissivity variations that could be achieved by raising the internal reference temperature of the spectrometer from 77°K to around 270°K. The results were predictable but none the less dramatic, and the philosophy of using a small  $\Delta T$  between sample and reference was incorporated in the design of the C.V.F. spectrometer described elsewhere in this report.

The experimental procedure was similar to that used in the field. Naturally-rough sample-rocks were allowed to warm up in sunlight, where they could radiate over most of the  $2\pi$  steradians into a clear sky. As each sample was examined by the spectrometer, it was placed on a background board sprayed with 3M's black paint. In this way, the spectrum of the sample would not be modified severely even if it did not fill the field of view of the spectrometer. The format of the supporting data taken while the spectrometer was in operation is given in figure 1. Examples of the reduced spectra are given in figures 2-10. In these spectra only the shape has significance, the absolute value of emissivity has not been calculated, --relative values however are meaningful.

A few words on this subject are perhaps timely. Referring to figure 11, the raw spectra for a black body and a sample at the same temperature are shown as  $(R_{BB}-R_{ref})$  and  $R_s-R_{ref}$  respectively, when

$R_{BB}$  = radiance of black body at temperature  $T_1$

$R_s$  = radiance of sample at temperature  $T_1$

$R_{ref}$  = radiance of black body reference at temperature  $T_2$

Since this type of spectrometer always chops against a reference the values shown on this figure represent the difference between reference and target energy.

FIELD GROUND DATA LOG:

[illegible]

Fig. 1 Typical Format of Supporting Data for Infrared Spectrometer.

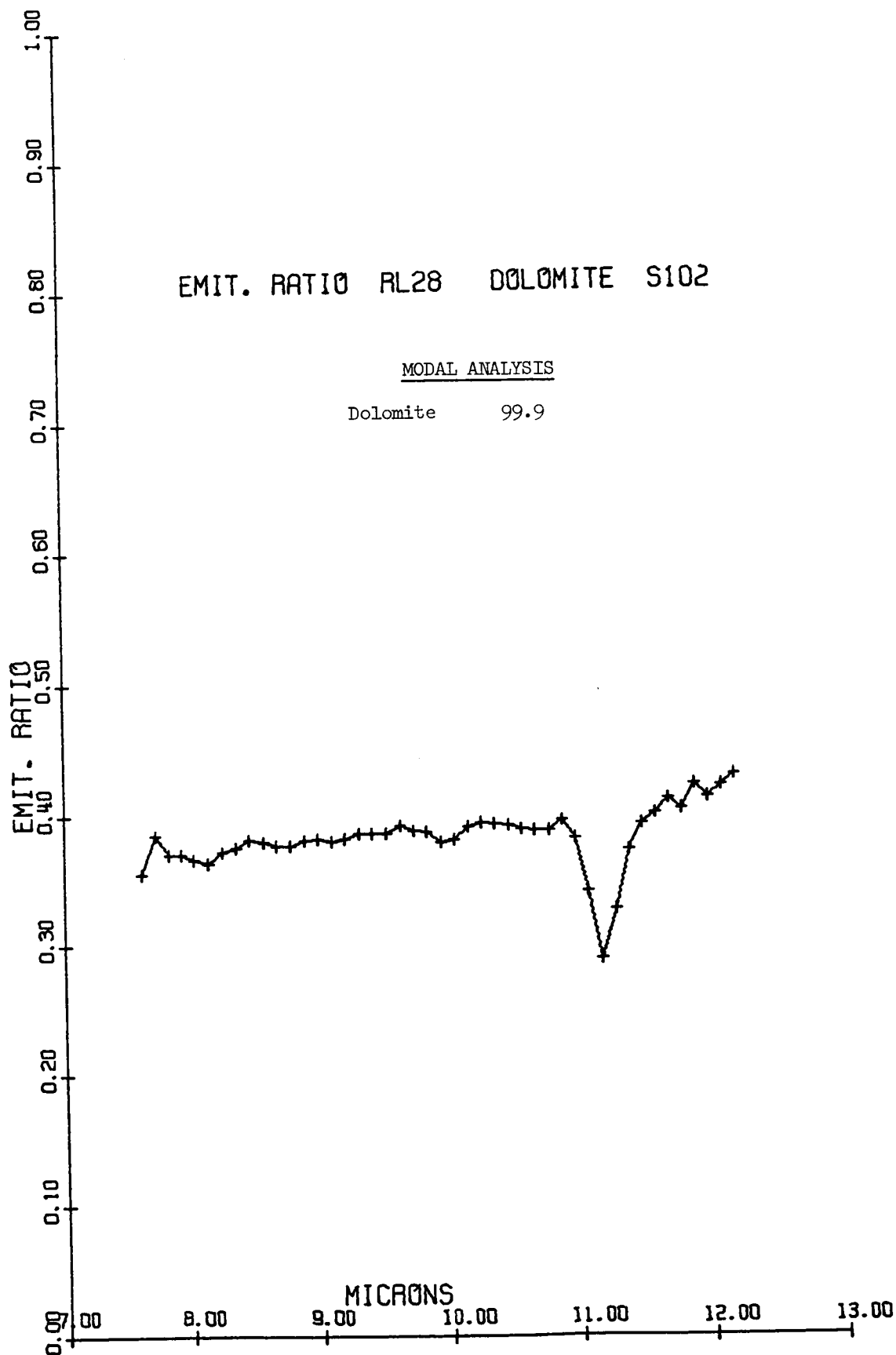


Fig. 2 Relative Spectral Emissivity of Dolomite

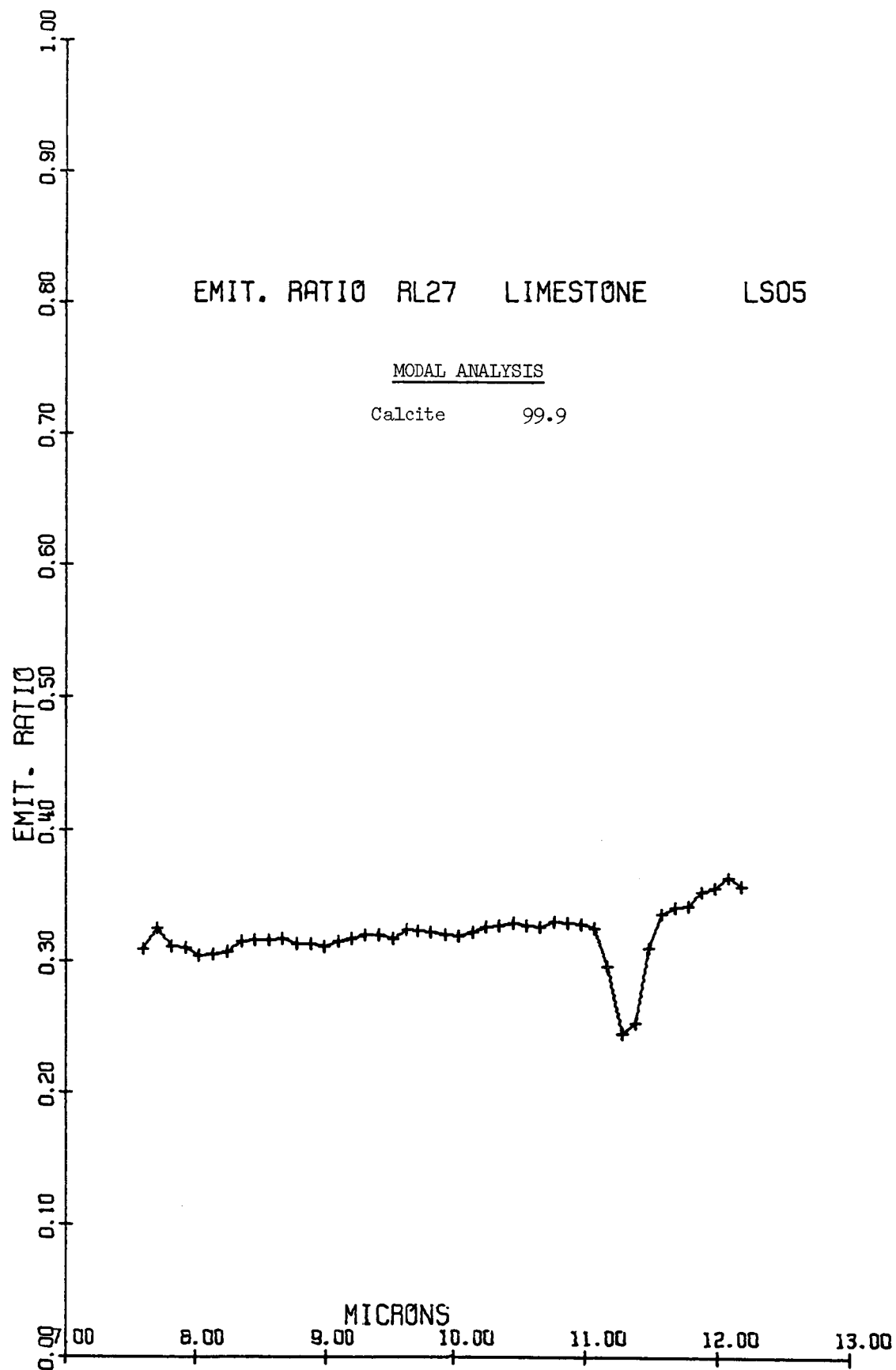


Fig. 3 Relative Spectral Emissivity of Limestone

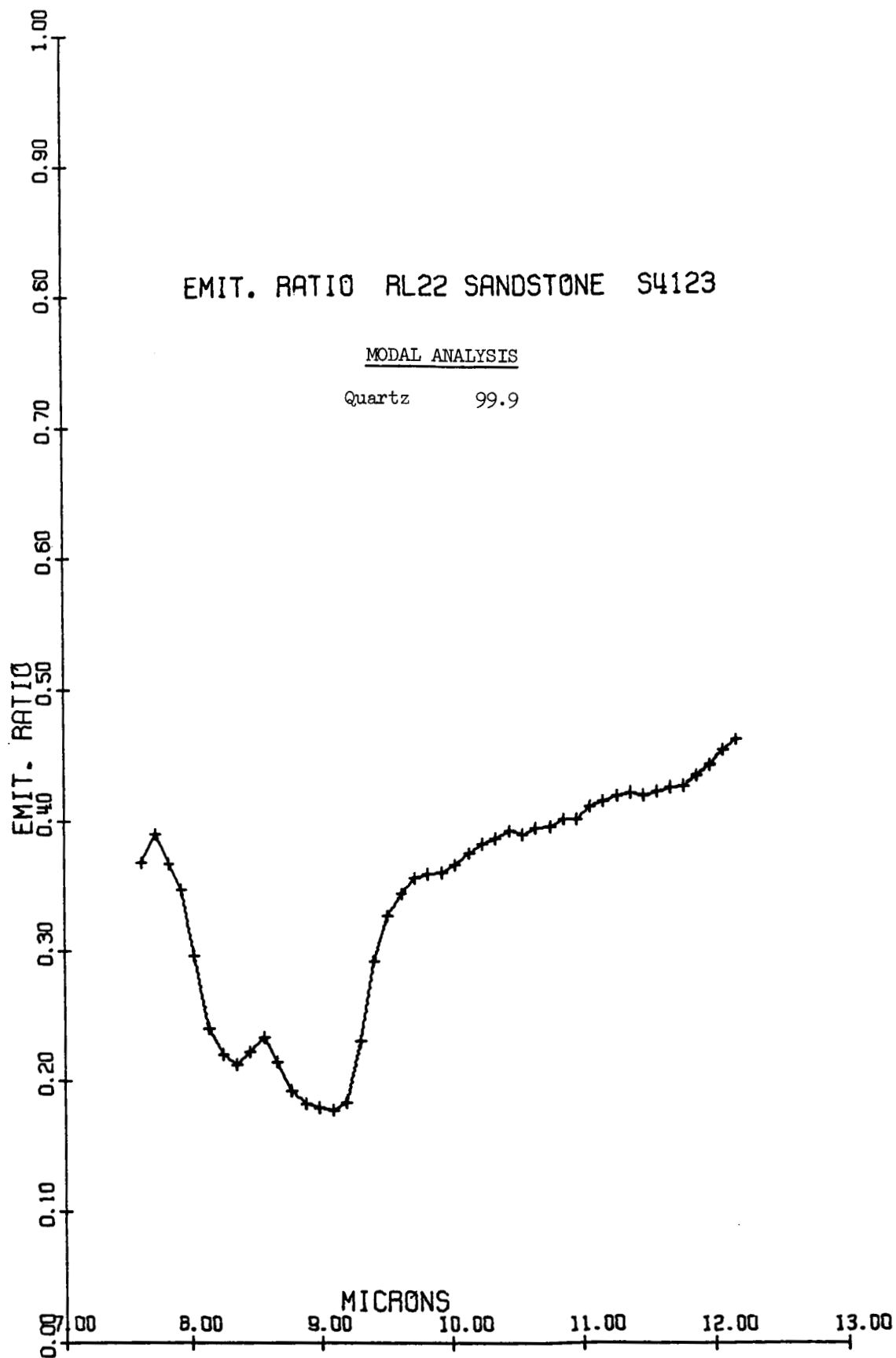


Fig. 4 Relative Spectral Emissivity of Sandstone



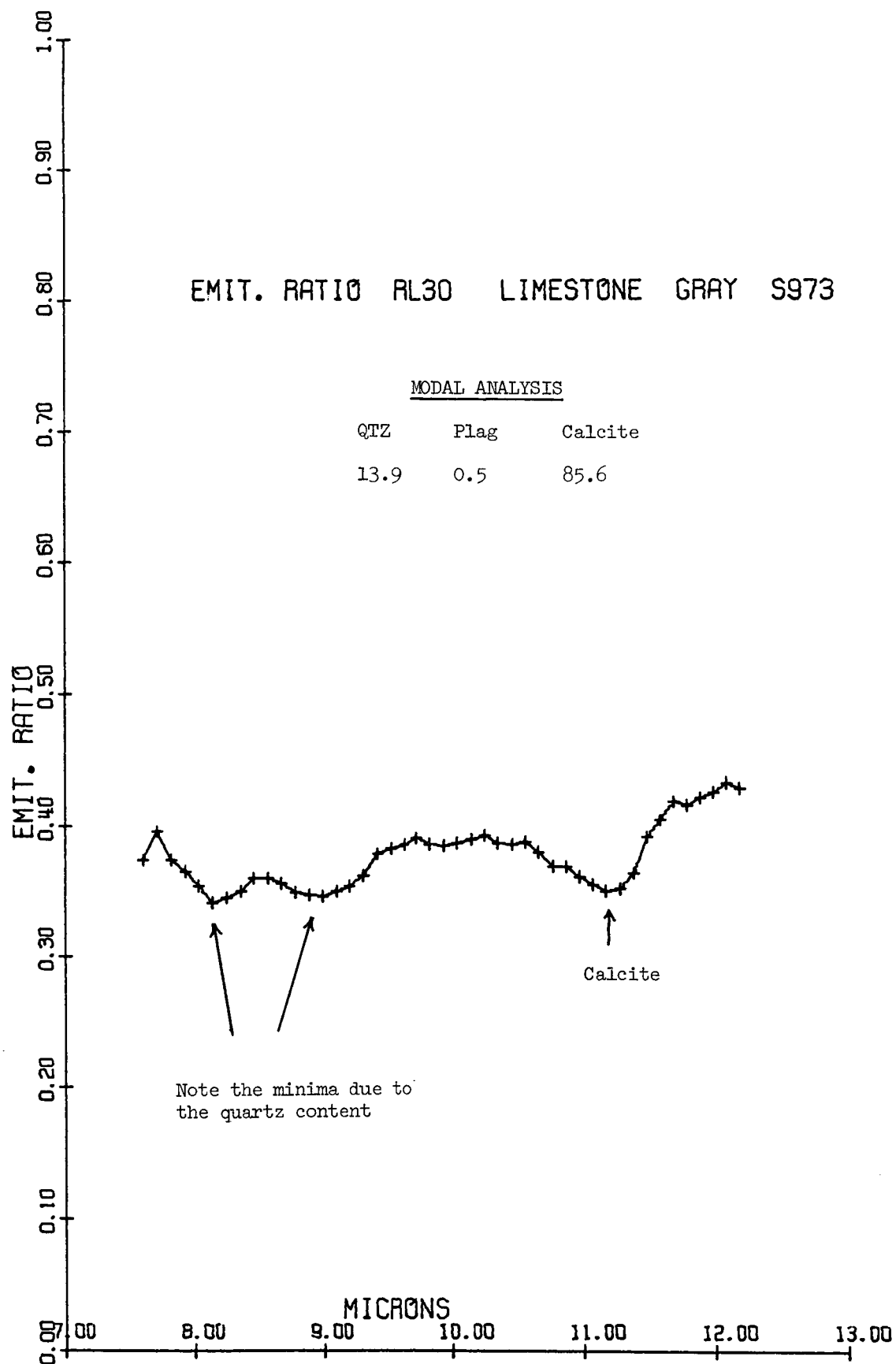


Fig. 5 Relative Spectral Emissivity of Limestone Gray (silicified)

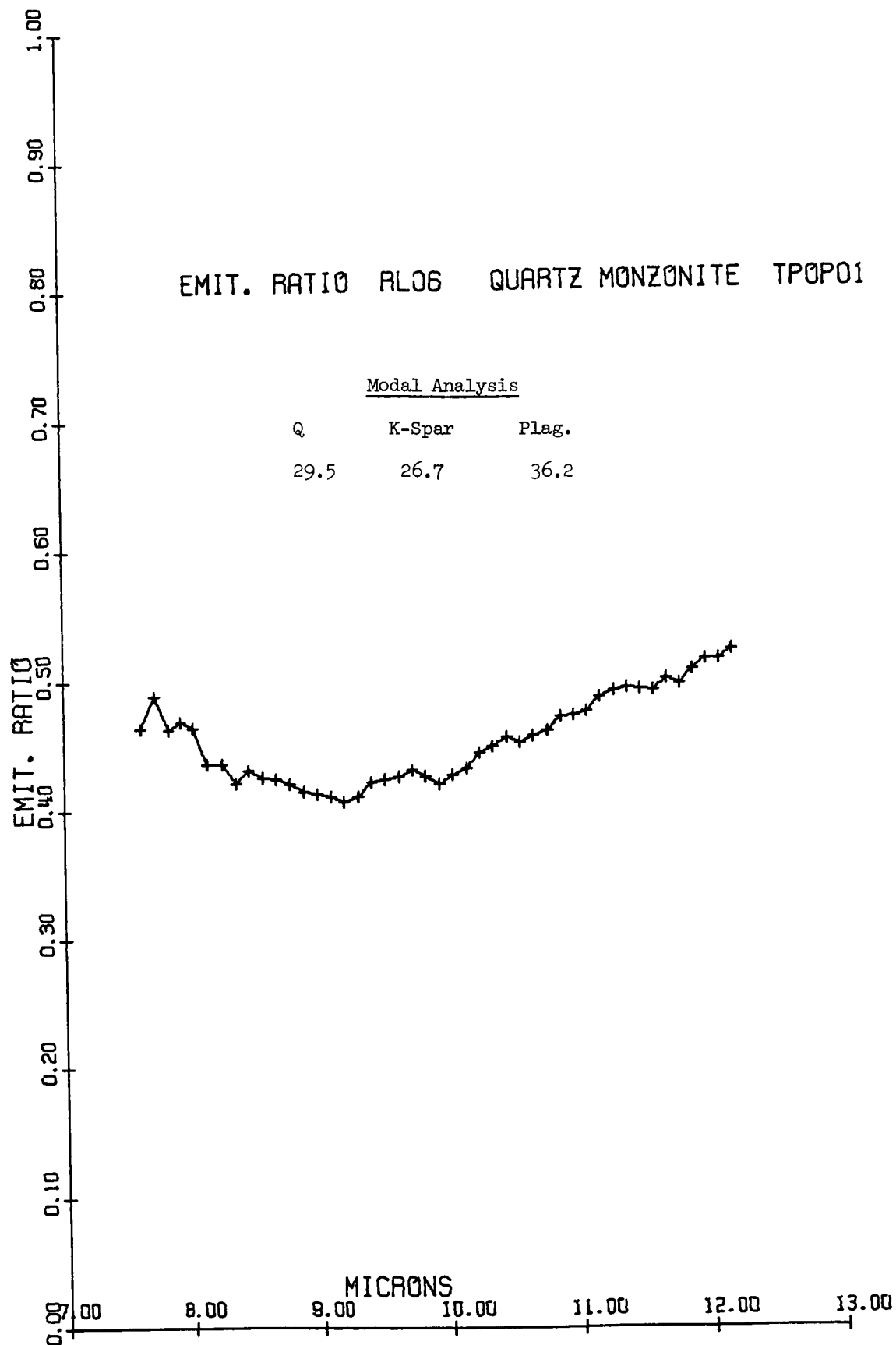


Fig. 6 Relative Spectral Emissivity of Quartz Monzonite

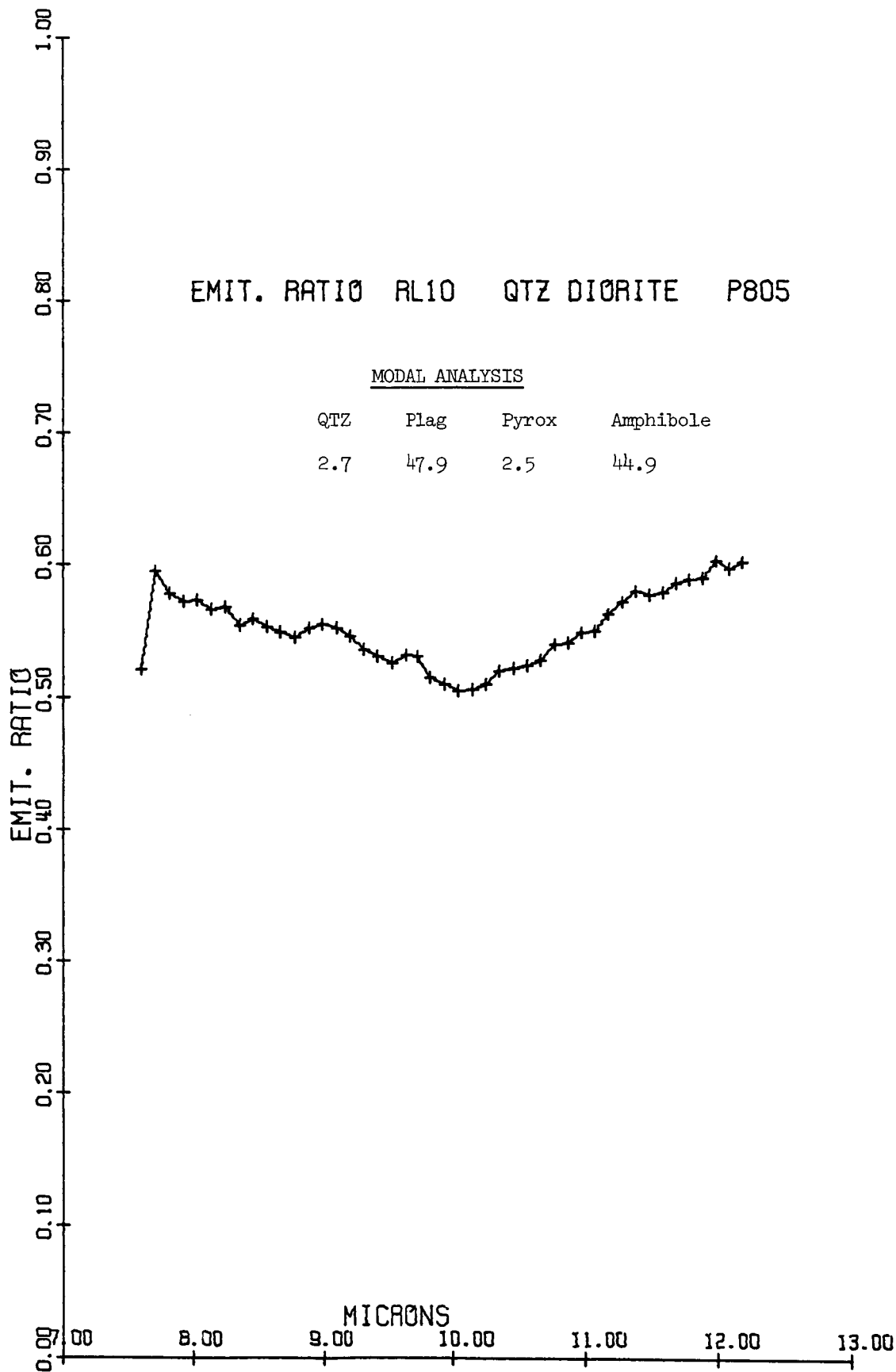


Fig. 7 Relative Spectral Emissivity of Qtz Diorite

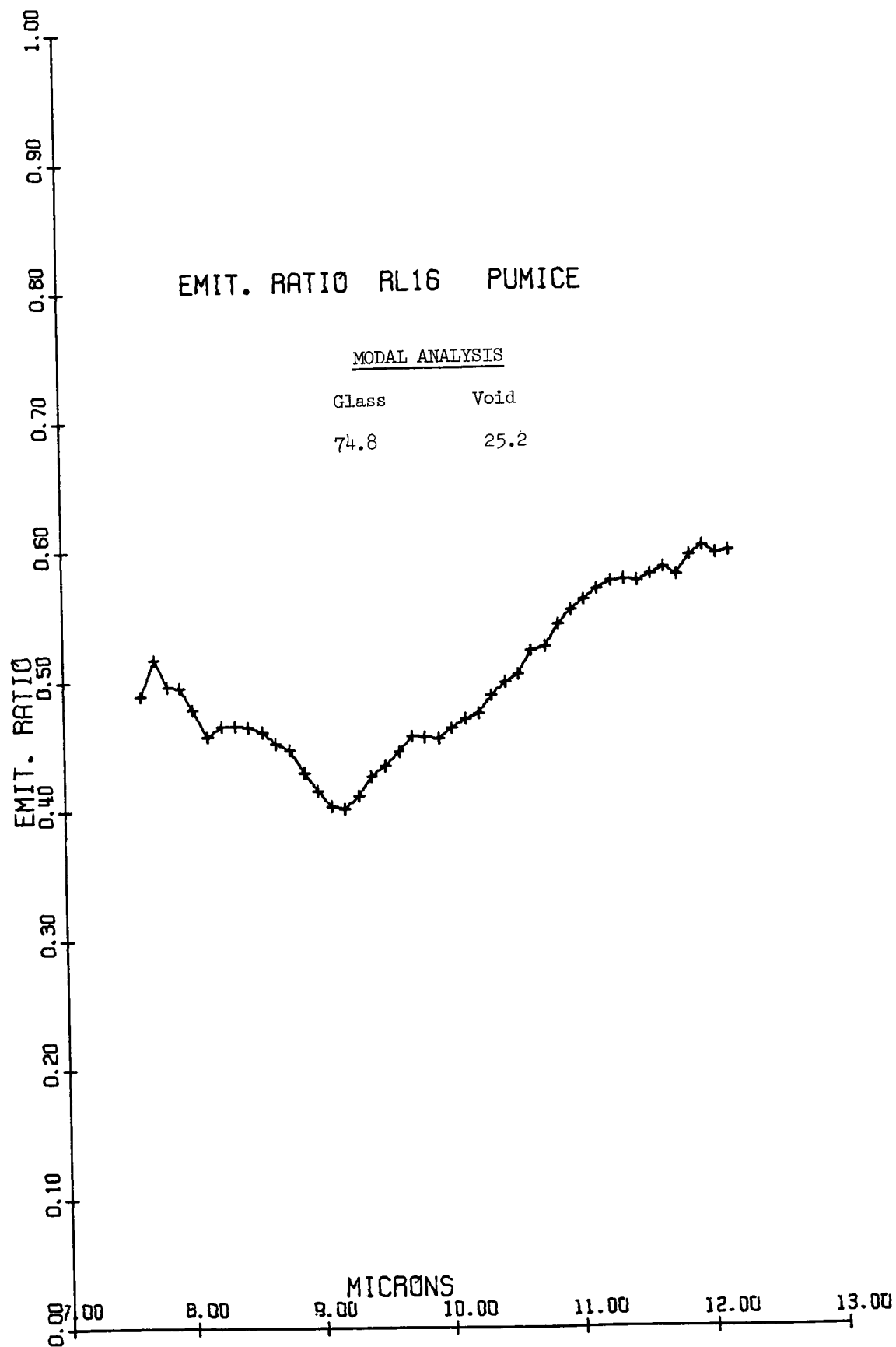


Fig. 8 Relative Spectral Emissivity of Pumice

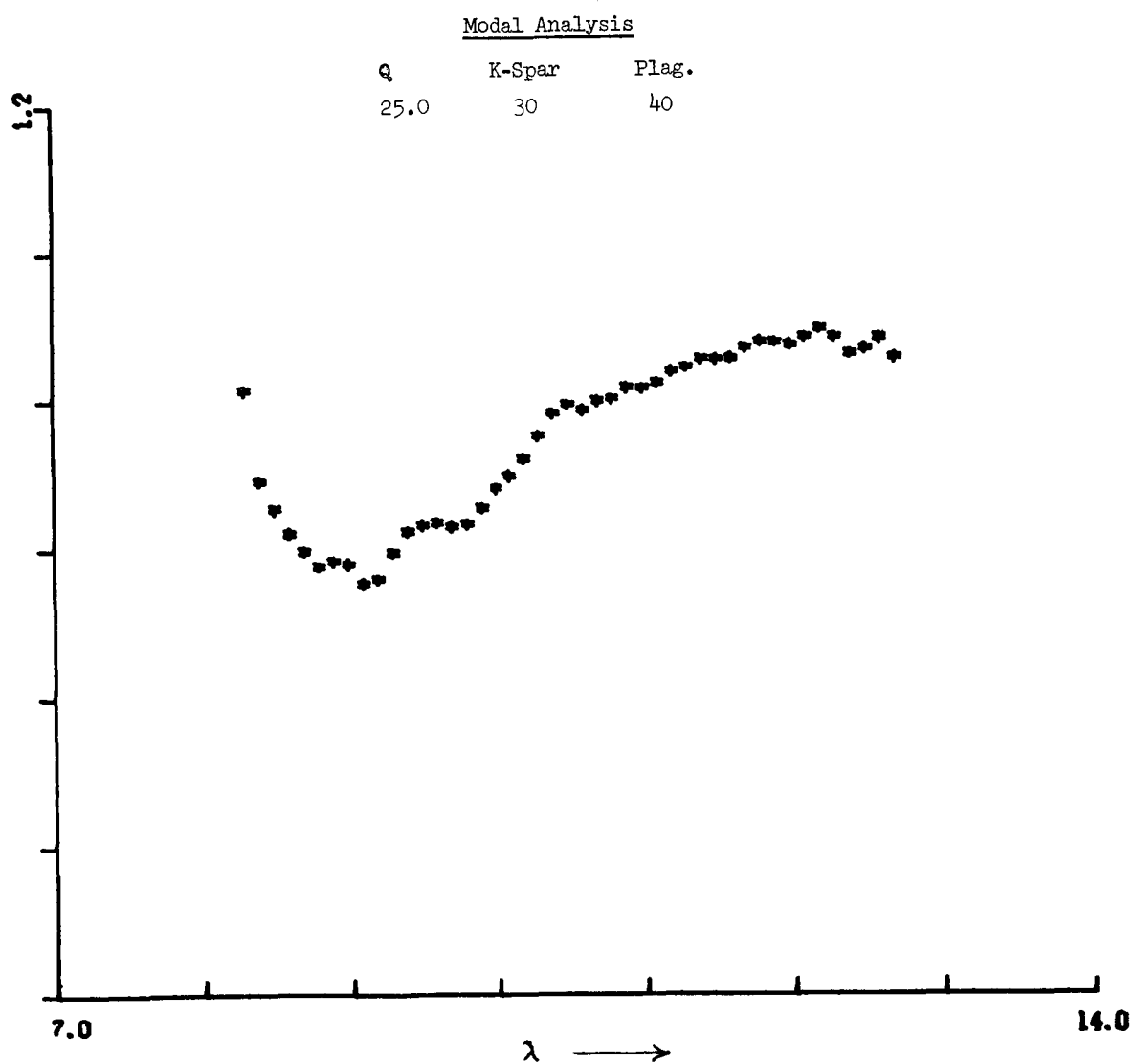


Fig. 9 Spectral Emissivity of Polished Quartz Monzonite  
(cold reference)

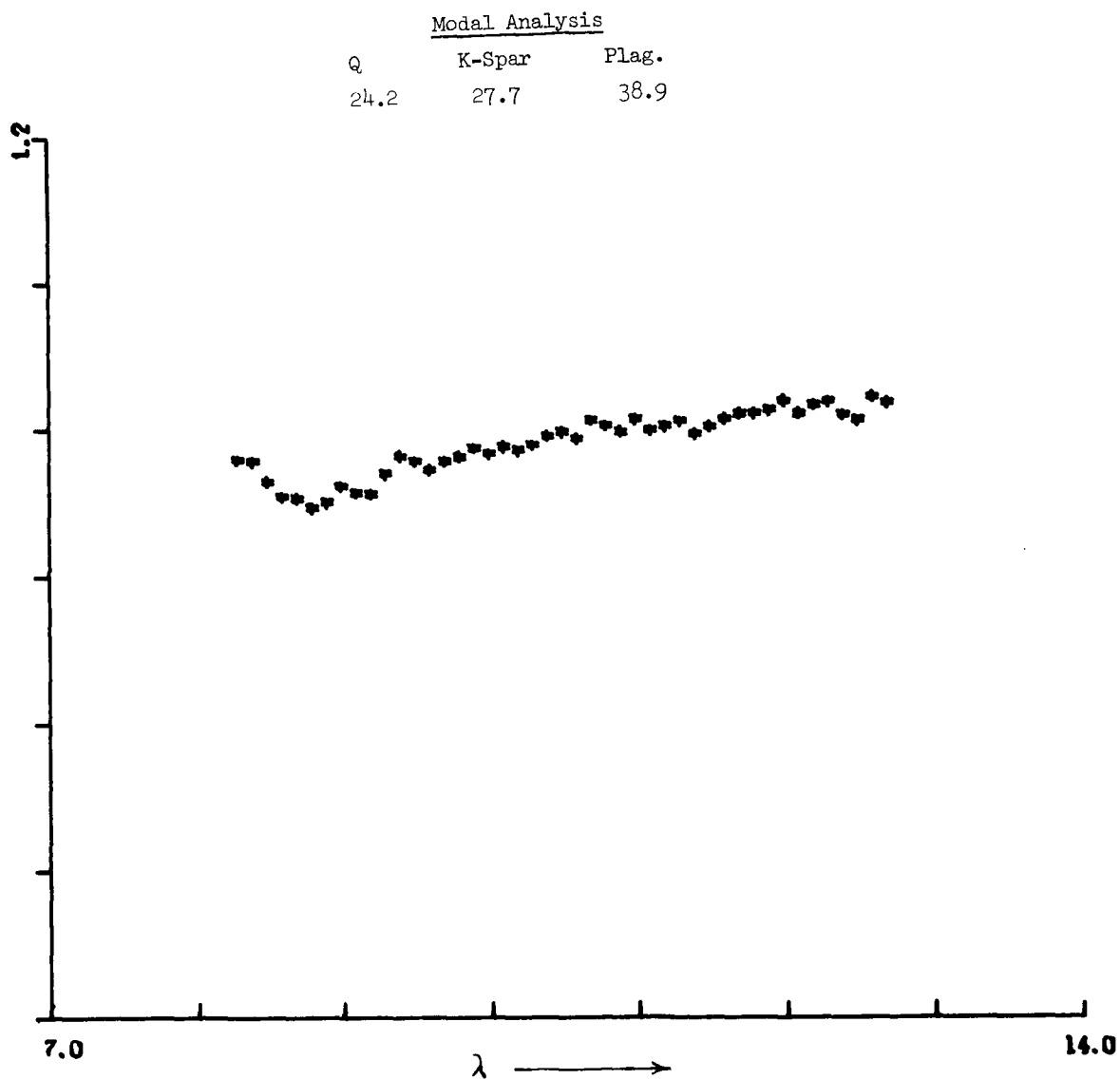


Fig. 10 Spectral Emissivity of Rough Quartz Monzonite  
(cold reference)

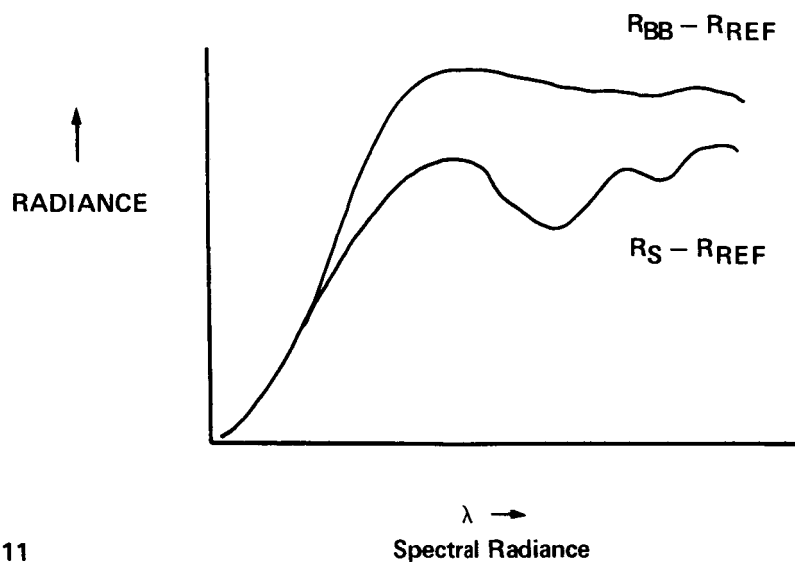


Fig. 11

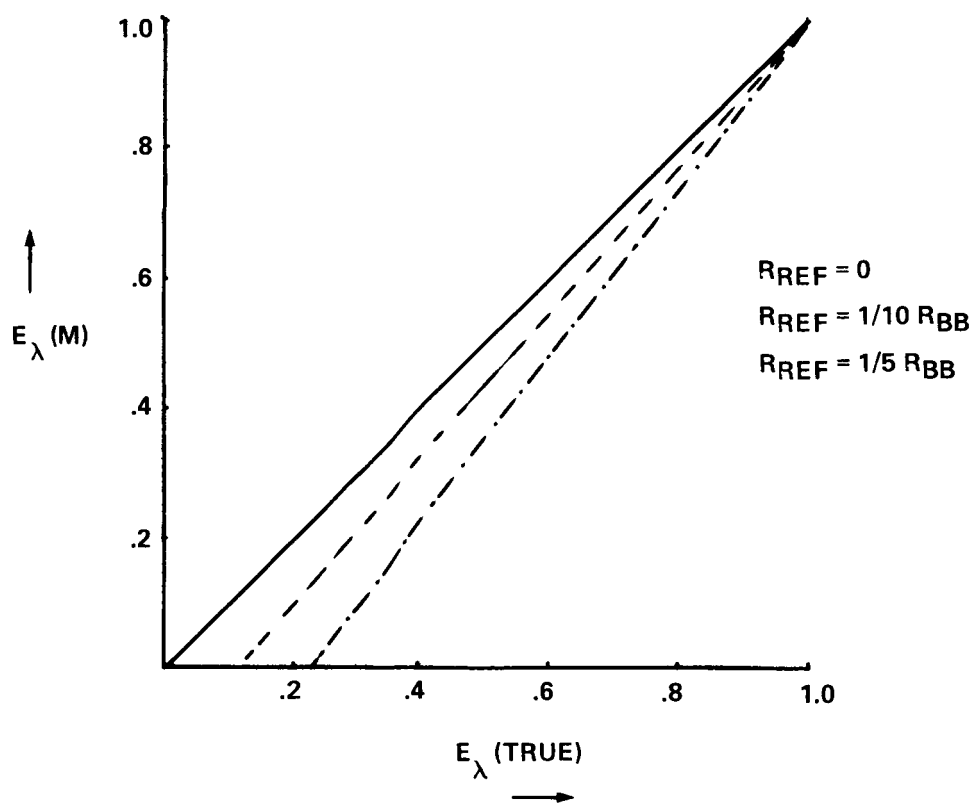


Fig. 12 True versus Measured Emissivity for Various Reference Radiance Levels

The emissivity ratio is  $\frac{R_s - R_{ref}}{R_{BB} - R_{ref}}$

Only when  $R_{ref}$  is  $\ll R_{BB}$  and  $R_s$  can the ratio  $\frac{R_s}{R_{BB}}$  be called the emissivity ratio. Our SG-4 originally had a nitrogen cooled (77°K) reference, and to a first approximation, this condition applied. In the case of a substantial contribution from the reference, then an adjustment must be made to obtain the real value of emissivity. A graph for making this correction is given in figure 12, where

$$E_{\lambda} \text{ m} = \text{measured } \frac{R_s}{R_{BB}}$$

and  $E_{\lambda} \text{ true} = \text{correct emissivity.}$

It can be seen from this graph that the errors in the uncorrected ratio decrease as the value of  $E_{\lambda}$  increases. One important point that is immediately apparent is that one only needs one calibration point for a given reference temperature to determine the slope of the graph and hence determine the true emissivity of the sample, since at the  $E_{\lambda} = 1$  end of the graph it is fixed. We propose building a simple checkerboard pattern of 3M's coated aluminum honeycomb ( $\epsilon = 1$ ) and gold plated copper ( $\epsilon = 0$ ), that should have an effective emissivity of 0.5. The temperature of this grey body will of course be the temperature of the 3M coated portions. Such a gray body was not available at the time the library samples were investigated, hence the absolute values of emissivity on these samples is not known from that data.

Referring to the figures 2-10 it can be seen that the spectral contrast is indeed enhanced. The spectral features around  $11.2\mu$  in the calcite and dolomite spectra are second order absorptions and yet are still plainly visible. For comparison figures 9 and 10 were added. These were taken with the same instrument using a 77°K reference. Fig. 9 is of a polished sample and fig. 10 of a rough sample. It can be seen that the improvement due to raising the reference temperature is approximately equivalent to polishing the



sample. Examples for rocks such as calcite show the same effect.

#### IV. a) THE CIRCULAR VARIABLE FILTER SPECTROMETER

The present status of this instrument is that having been assembled and tested once, it has been disassembled for final machining, and is now complete again except for three circuit boards. (See figure 13). The associated data system which will be used both with the instrument and the existing SG-4 spectrometer is also near completion. It has, in our estimation, been worthwhile to wait for the upgraded system before taking large quantities of spectra. Early attempts to examine the spectra of powdered samples, using the SG-4 and X-Y plotter were not very successful as described earlier.

It is anticipated that for some applications the CVF instrument will become the prime system for obtaining spectra, and that the SG-4 will be relegated to the position of a back-up system. A description of the CVF spectrometer follows. The optical design is a modified version of a design provided by Warren Hovis (NASA/GSFC).

#### b) THE CVF SPECTROMETER OPTICAL SYSTEM: (see figure 14)

The Fore optics for this instrument is a 4" focal length  $f$  1.5 cassegrain, (usually to be found in the front end of a Barnes Engineering 4" radiometer). Chopping occurs at the first focal plane, and the incident energy bundle is then refocused into the CVF by a KRS-5 field lens. The detector presently in situ (a Servo-Corp immersed thermistor\*) has its own supplementary lens which focuses the bundle emerging from the filter wheel.

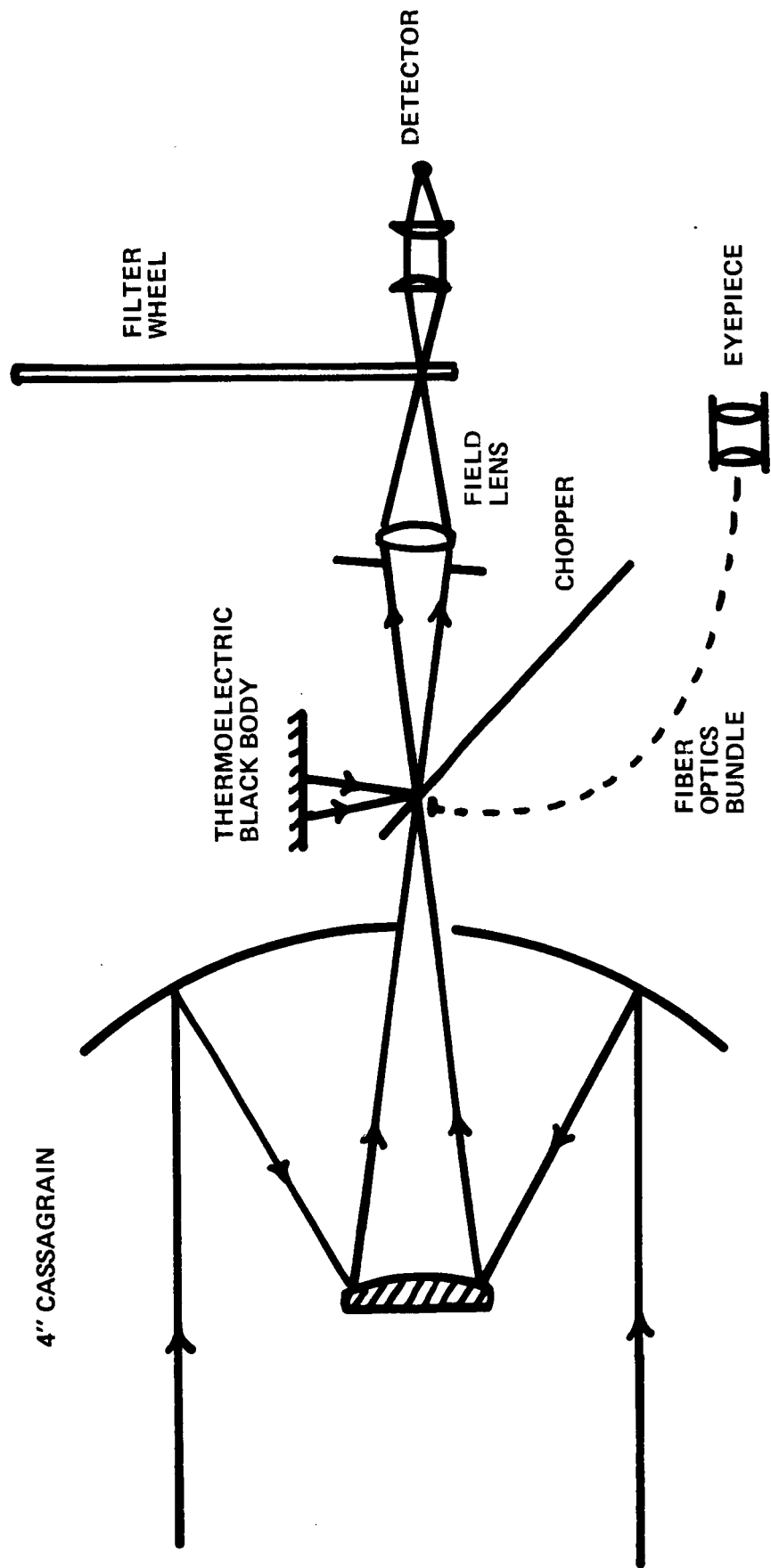
The reference body is a thermo electric element coated with 3M's black, bolted to a substantial heat sink. The element is capable of being driven at approximately 20°C below ambient, which should be ample for rock and powder measurements. Energy from this source is reflected from a gold plated chopper into the optical train.

One of the more tiresome problems with our SG-4 spectrometer has been the difficulty of aligning the infrared and optical view-

(\* on loan from W. Hovis GSFC)



Fig. 13 The CVF Spectrometer



OPTICS SCHEMATIC FOR C.V.F. SPECTROMETER

Fig. 14

finder fields of view, since the viewfinder employs a swinging mirror, the seating of which is critical. In the CVF instrument, the viewfinder image is picked off the reverse side of the chopper and relayed by an imaging fibre optics bundle to a suitable eyepiece. The resolution of the bundle is over 500,000 fibres per inch.

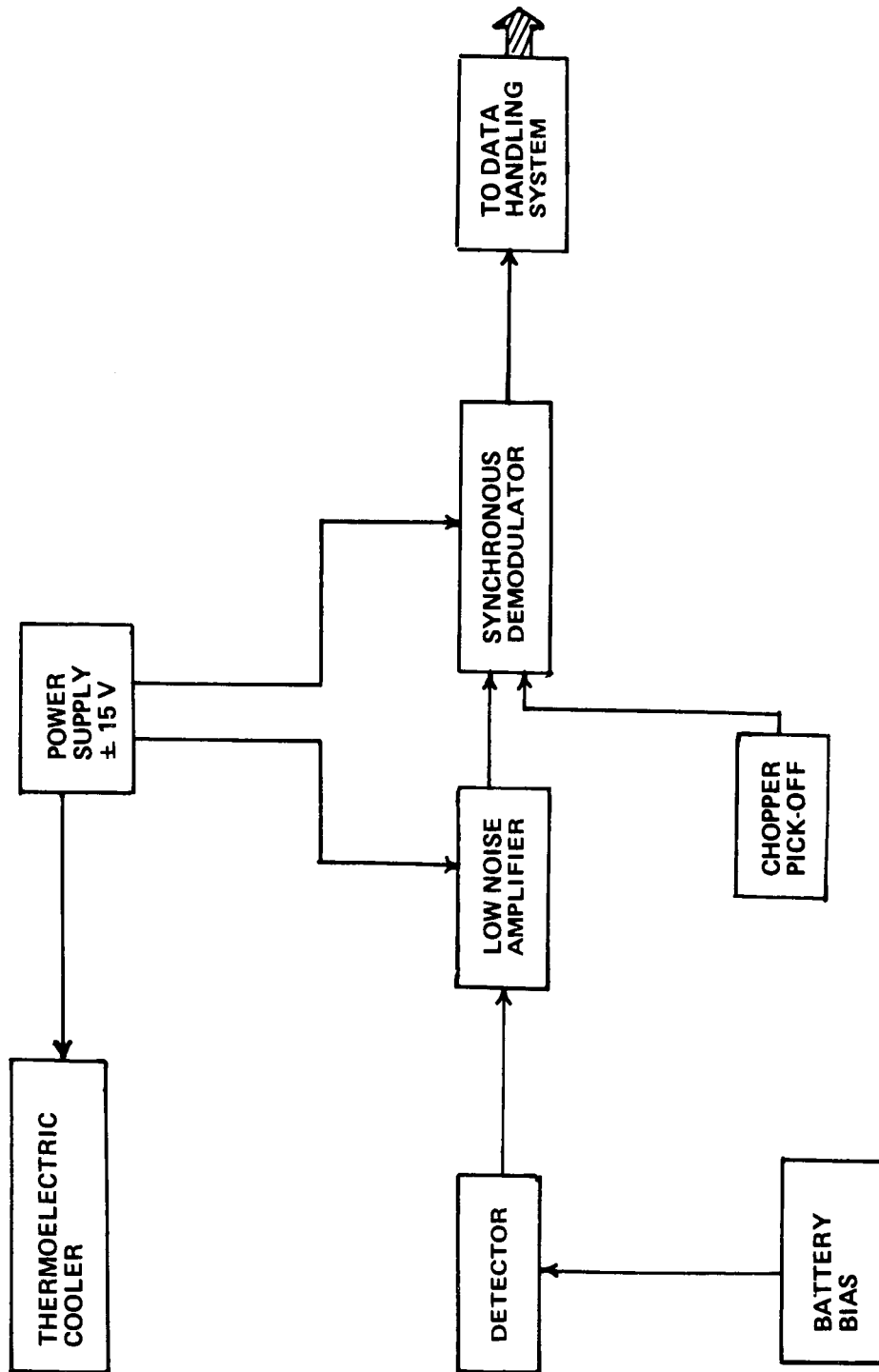
Focusing is from infinity to 5 ft., although the image degradation, due primarily to spherical aberration of the field lens, may limit the useful focusing range to something more like infinity to 10ft.

### c) THE ELECTRONICS SYSTEM

The signal processing electronics for this instrument (see fig. 15) is built up from a series of standard modules. The detector feeds into a miniature preamplifier fitted inside the detector housing and from there on to an Ithaco amplifier type 254. Synchronous demodulation is achieved by another Ithaco unit model 351. Either polarity of demodulation is available from this unit, which eases the problem of computer reduction for such things as sky spectra, where the source is colder than the reference. The reference signal for the demodulator is derived from a phototransistor-lamp combination mounted on the chopper housing. The chopping frequency is presently 30 HZ which leads to possible problems in rejecting (60 HZ) noise from improperly grounded or shielded components. This presently does not appear to be a severe problem however, and will disappear altogether if we decide to substitute a cooled CuGe detector, which requires chopping at around 2000 HZ.

Detector bias is provided by batteries ( $\pm 67V$ ) with a large capacitor strapped across them. This provides a convenient low impedance, stable, supply. For portable use, if this should be required, all electronics can be driven through some sort of regulation from  $\pm 15V$  batteries. In this case however, some provision would have to be made for supplying the 115VAC for the two synchronous drive motors.

Temperature control for the reference is provided by an operational amplifier controlling the high current drive transistor



C.V.F. SPECTROMETER ELECTRONICS

Fig. 15

(up to 5 amps). The error signal for this amplifier is produced by a thermistor attached to the reference surface, and wired into a simple bridge circuit. Temperature adjustment is of course achieved by deliberately unbalancing the bridge. The circuit is a development of one designed for detector cooling by Develco Inc. under a sub-contract from NASA grant, NGR-05-115-020. This grant has also paid for most of the hardware for the spectrometer.

#### d) THE DATA HANDLING SYSTEM

It is in this portion of the design that the CVF spectrometer really scores over reciprocating grating instruments, for if a CVF which is locked onto the same shaft as a digital shaft encoder, one has a unit that can be repeatedly indexed to pass any wavelength required. Conversely, the unit always has a unique digital readout of wavelength (via a conversion table of  $\theta$  versus  $\lambda$  - see fig. 16). Only experimenters who have wrestled with the problem of mating a computer with IR instruments with analog wavelength readout can appreciate the simplicity of using direct digital readout.

Referring to figure 17, the encoder output appears as a series of pulses which are used to trigger an analog to digital converter. The converter samples the spectrometer, a radiometer, and a series of hand switches which are used for such things as identification data. Wavelength data need not be sampled, as it is inherent in the sequential series of radiance samples. The digital information is then recorded on a Kennedy 1400 incremental recorder. The tapes from the machine can then be directly read into the IBM 360 computer where they are processed by a high speed correlation program.

### V. STATUS OF OTHER EQUIPMENT RELEVANT TO THIS CONTRACT

#### SG-4 Spectrometer

This instrument is operational, and has been modified to accept a digital grating-position encoder. It is also now operated with a reference temperature close to ambient.

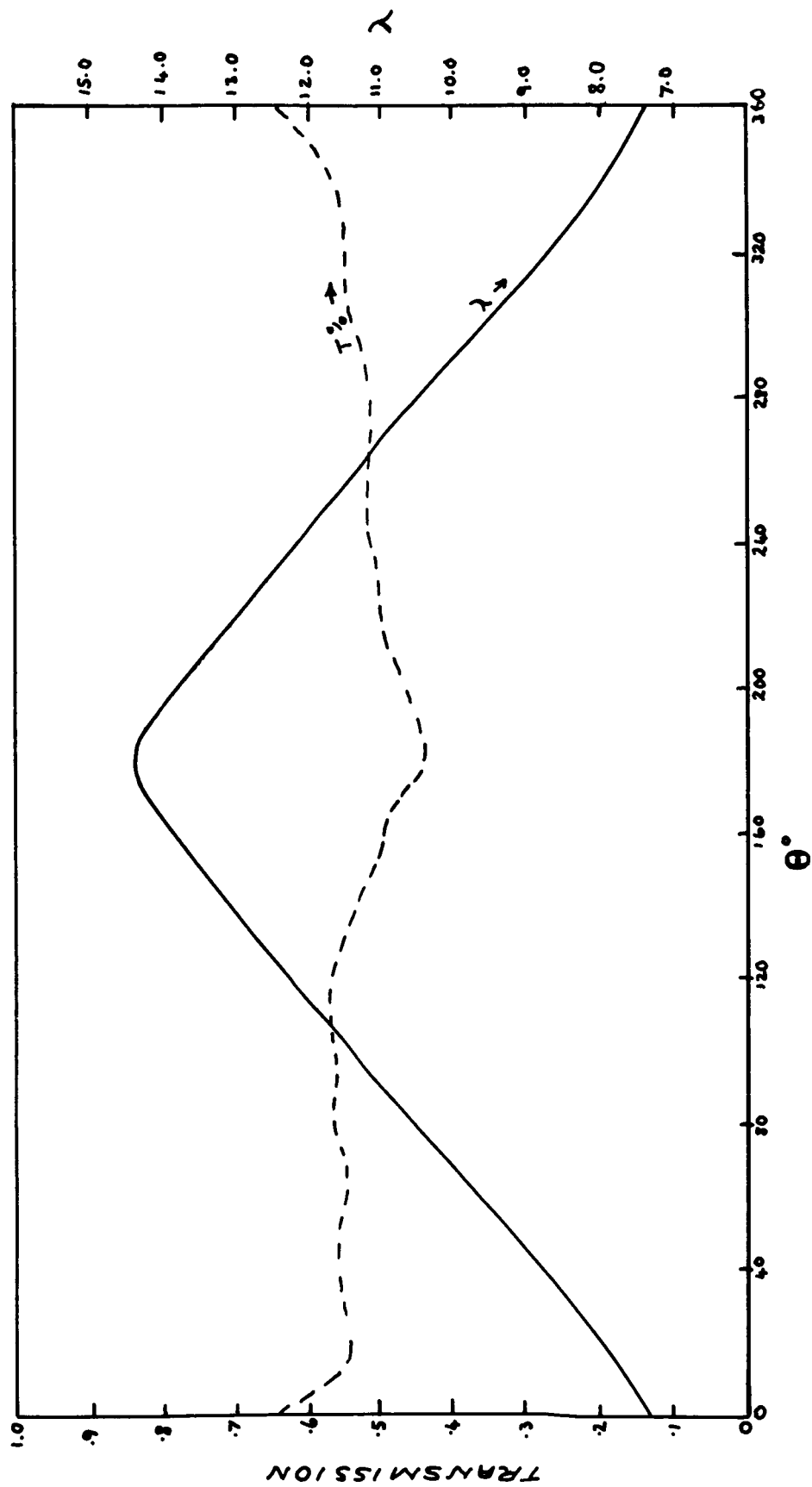
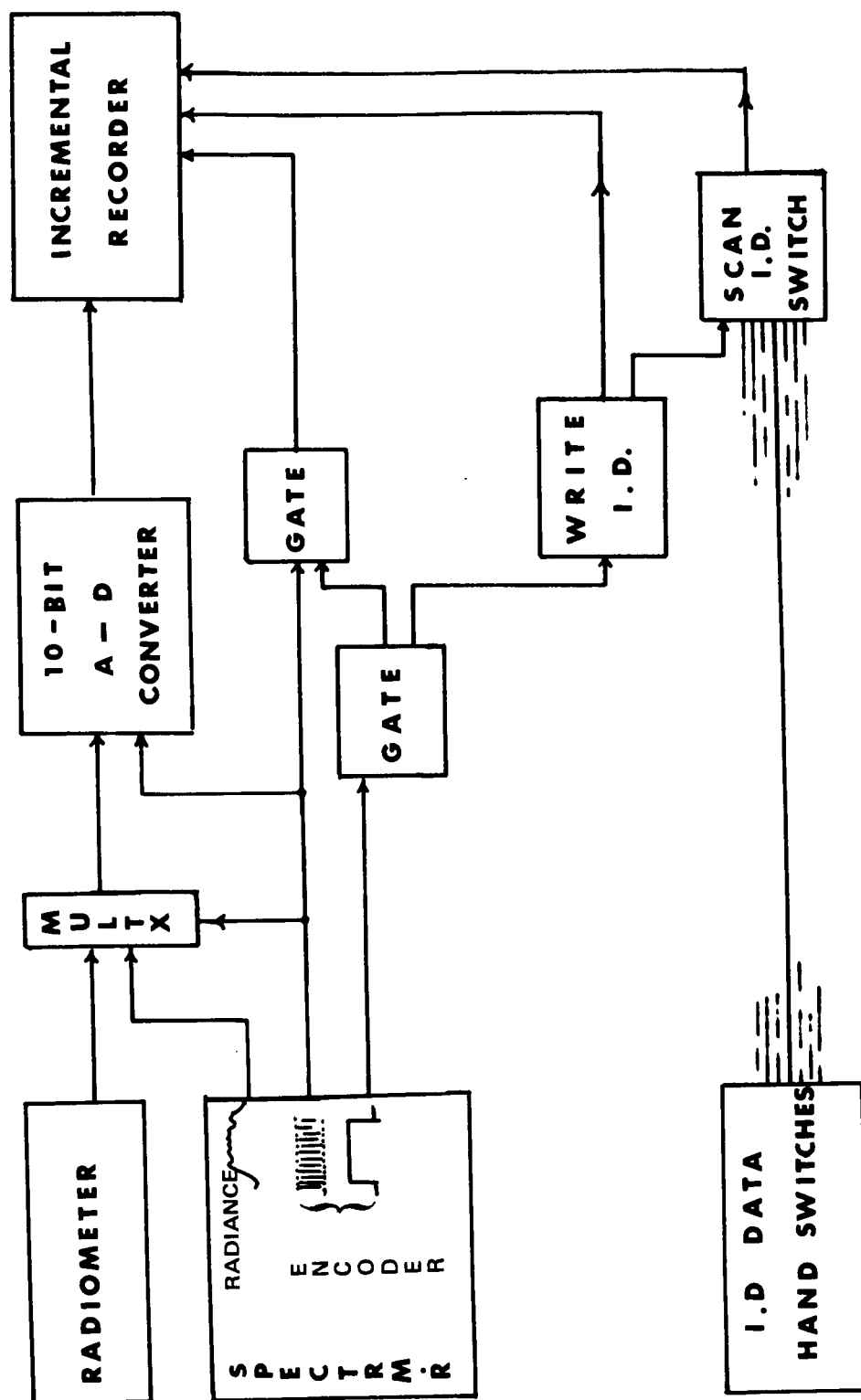


Fig. 16 Transmission vs Rotation for the Circular Variable Filter.



DATA FLOW DIAGRAM FOR C.V.F. SPECTROMETER

Fig. 17